Practical Field Alignment of Parabolic Trough Concentrators

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November 10, 2005

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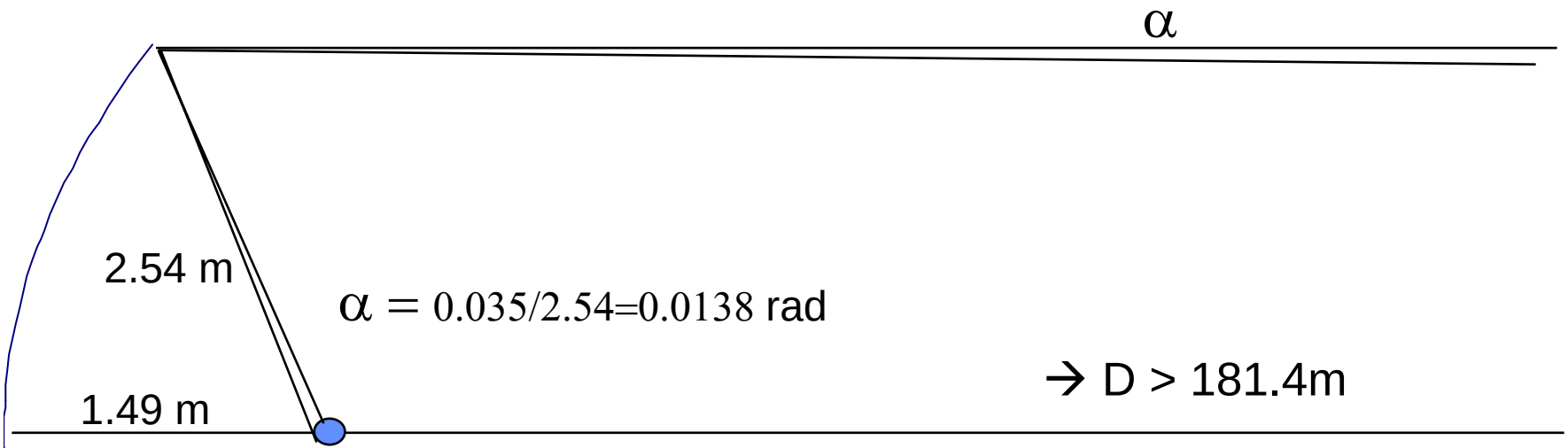
Trough Alignment - Background

- Accurate trough facet alignment is important
  - High intercept
  - Higher concentration possible
- Quantifying trough alignment is difficult
  - Linear nature of troughs makes alignment targets for VSHOT and other dish based techniques impractical
  - Distant viewer “look back” approaches also impractical
- Optical alignment inherently much more accurate than fixtures
- Practical optical technique could reduce fixturing accuracy and cost, increase intercept, and increase concentration

Trough Alignment- A "Dish Guy" Perspective



- Asked to calculate minimum distance to insure seeing tube in entire trough when viewed on axis
- Noted that if viewer is offset from optical axis, it is possible to "see" HCE image from close distance
- Simple easy-to-implement approach using "visual aids" like on dishes conceived

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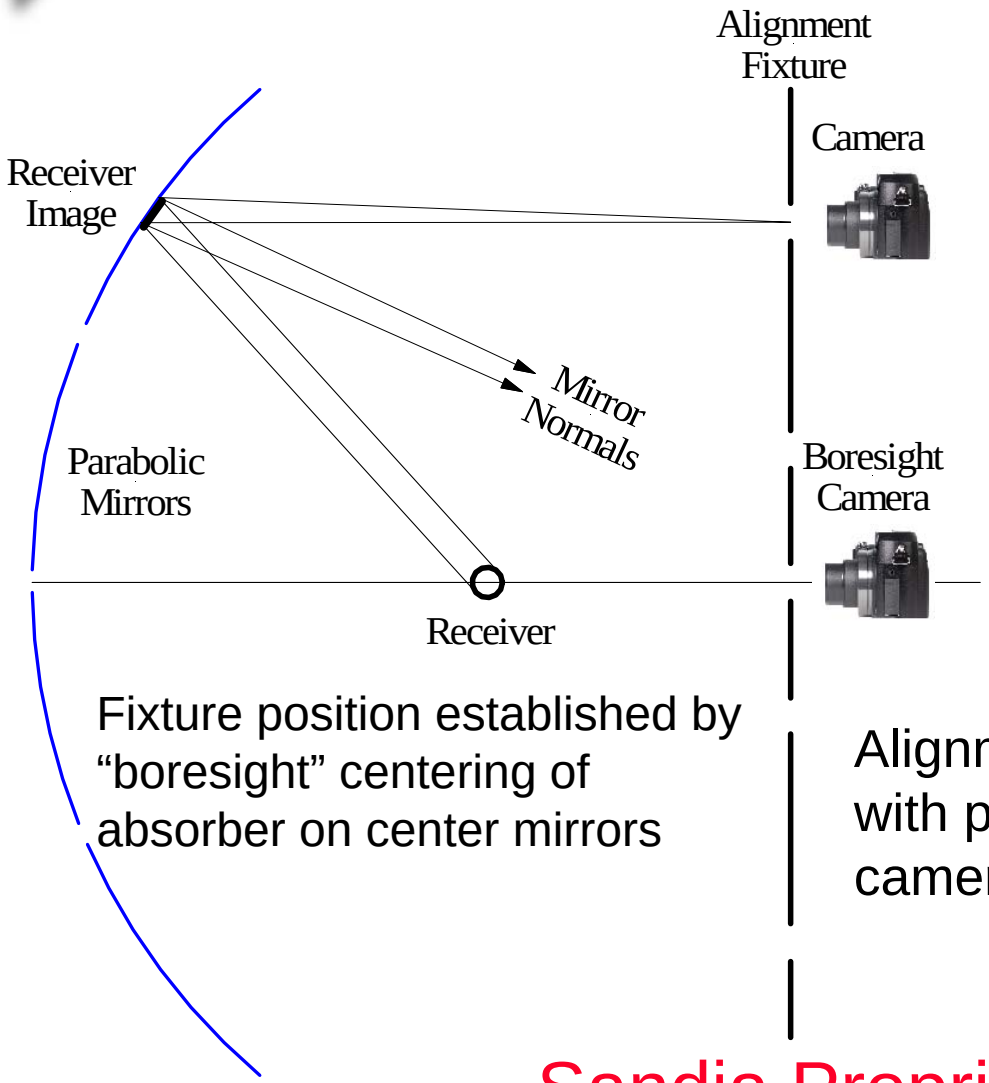
Theoretical Overlay Photographic (TOP) Alignment Technique



View from convenient distance at precise offsets from axis

Fixture location set with tape measure and levels

Fixture position established by "boresight" centering of absorber on center mirrors

Alignment fixture - a pole with precisely established camera offsets

Color Target Dish Alignment

- Technique similar the approach used on Remote Dishes
  - Theoretical color target mounted on engine
  - Dish, receiver and observer bore sighted with sight aids
  - Overlay image on dish
  - Adjust mirrors accordingly
- Accurate alignment with no “hot spots” on receiver

FY 05 TOP Alignment Objectives

- Explore the potential of the TOP alignment concept on parabolic troughs
  - Prototype technique on LS-2 module at the NSTTF
  - Develop “proof-of-principle” hardware and techniques
  - Develop understanding of potential capabilities and limitations
- Align LS-2 using TOP alignment and compare with distant observer and VSHOT
- If promising, develop “Field Deployment Prototype” system in FY 06
  - Test at Saguaro and Kramer Junction
  - Potentially develop module characterization capability (Tim Wendelin NREL)

TOP Alignment of LS-2 at NSTTF

- **Prototype fixture fabricated**
  - **1”x 3” Al tubing, Unistrut, & angle brackets**
  - **Heavy duty tripod**
  - **Mounted on stand to account for rotating platform**
  - **One middle (boresight) position**
  - **Four alignment positions centered on mirror rows**

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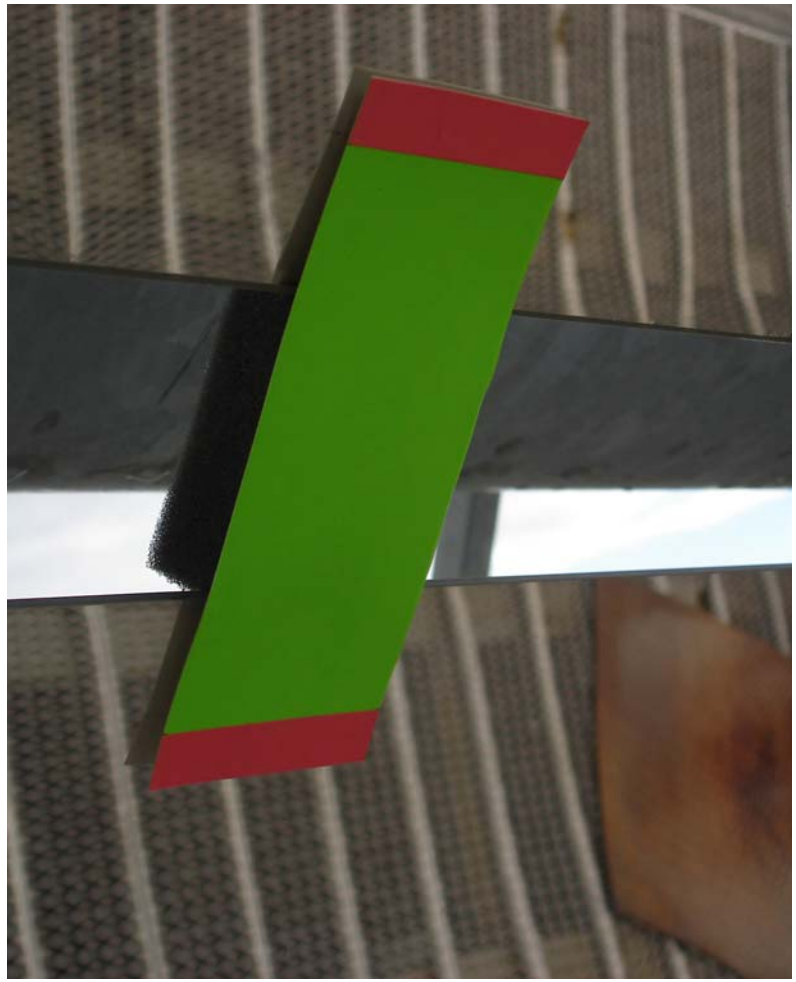
TOP Alignment of LS-2 at NSTTF (cont.)

- Boresight “visual aids” used to align trough, HCE, and fixture
- Mirrors inherently aligned to HCE
- Nikon D70 digital camera manually moved to each position
- Microsoft word used to overlay theoretical and photographic images



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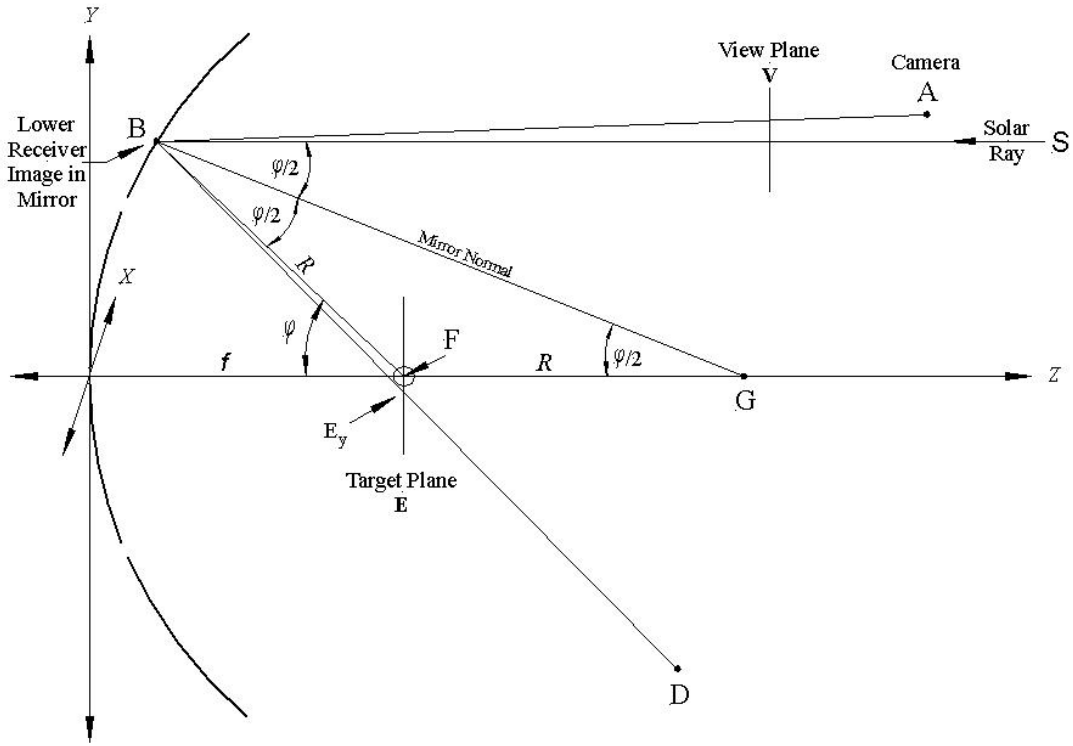
TOP Alignment of LS-2 at NSTTF (cont.)

- Vector algebra used to calculate theoretical overlays
- All alignment shims removed
- LS-2 alignment characterized with Distant Observer and TOP techniques
- LS-2 aligned by the TOP technique
  - 3 iterations (should be reducible to 1 or 2)
  - TOP and Distant Observer images compared at each step

$$\mathbf{BD} = 2\left[\frac{\mathbf{BA} \bullet \mathbf{BG}}{\mathbf{BG} \bullet \mathbf{BG}}\right]\mathbf{BG} - \mathbf{BA}$$



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TOP Alignment Results
Distant Observer (before)

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TOP Alignment Results
Distant Observer (after)

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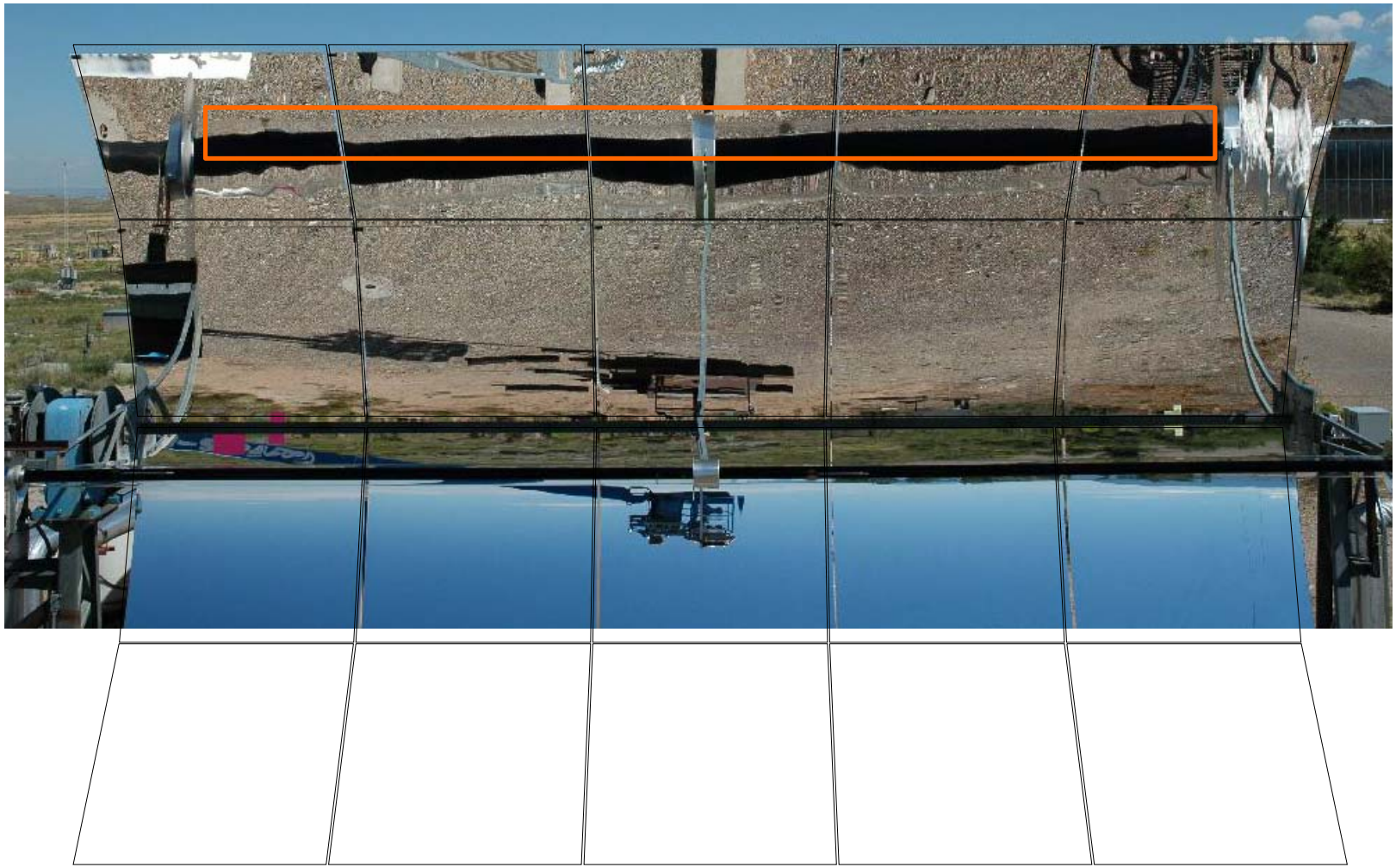
TOP Alignment
Top Outer Row (before)



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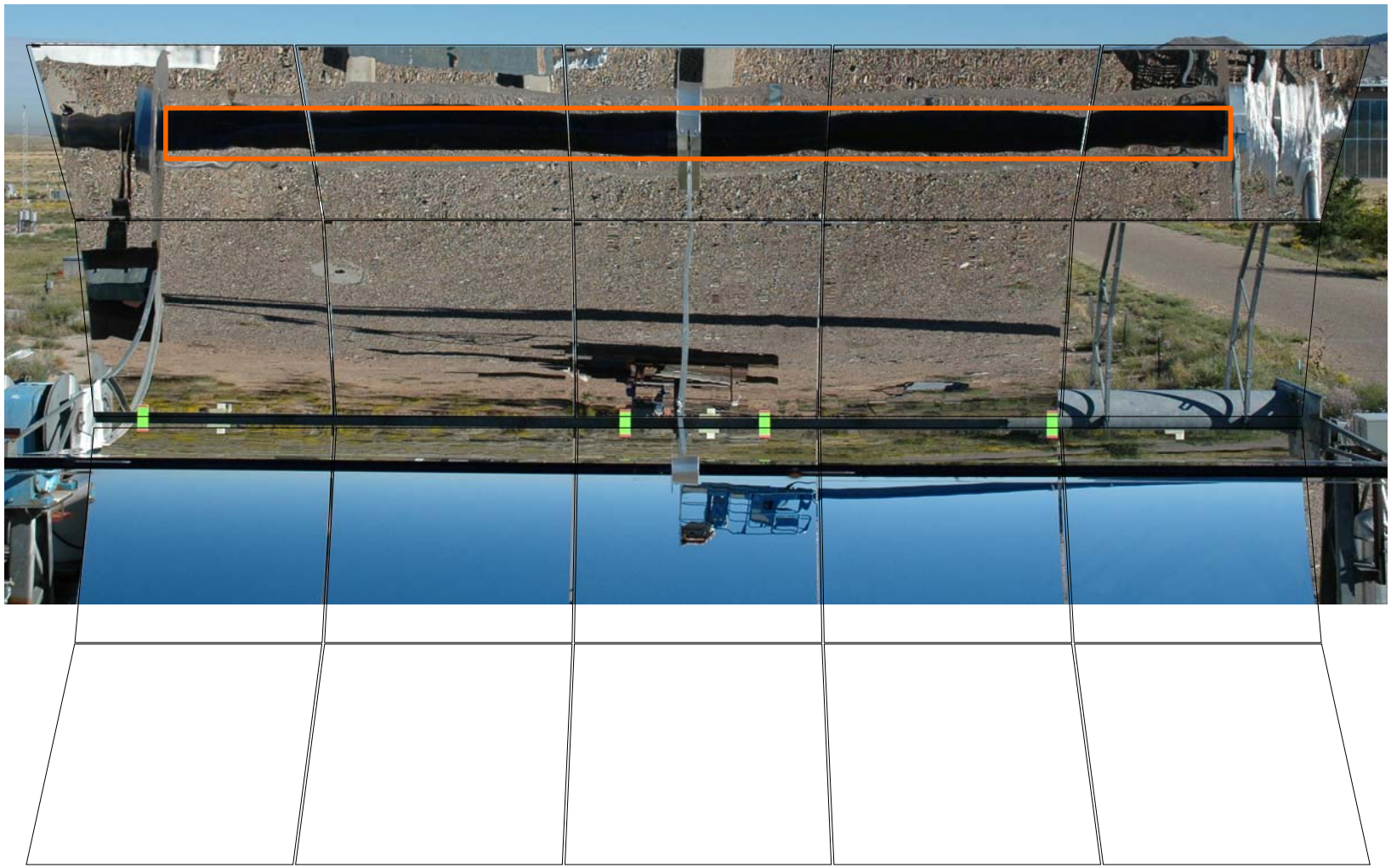
TOP Alignment
Top Outer Row (after)



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TOP Alignment
Bottom Outer Row (before)

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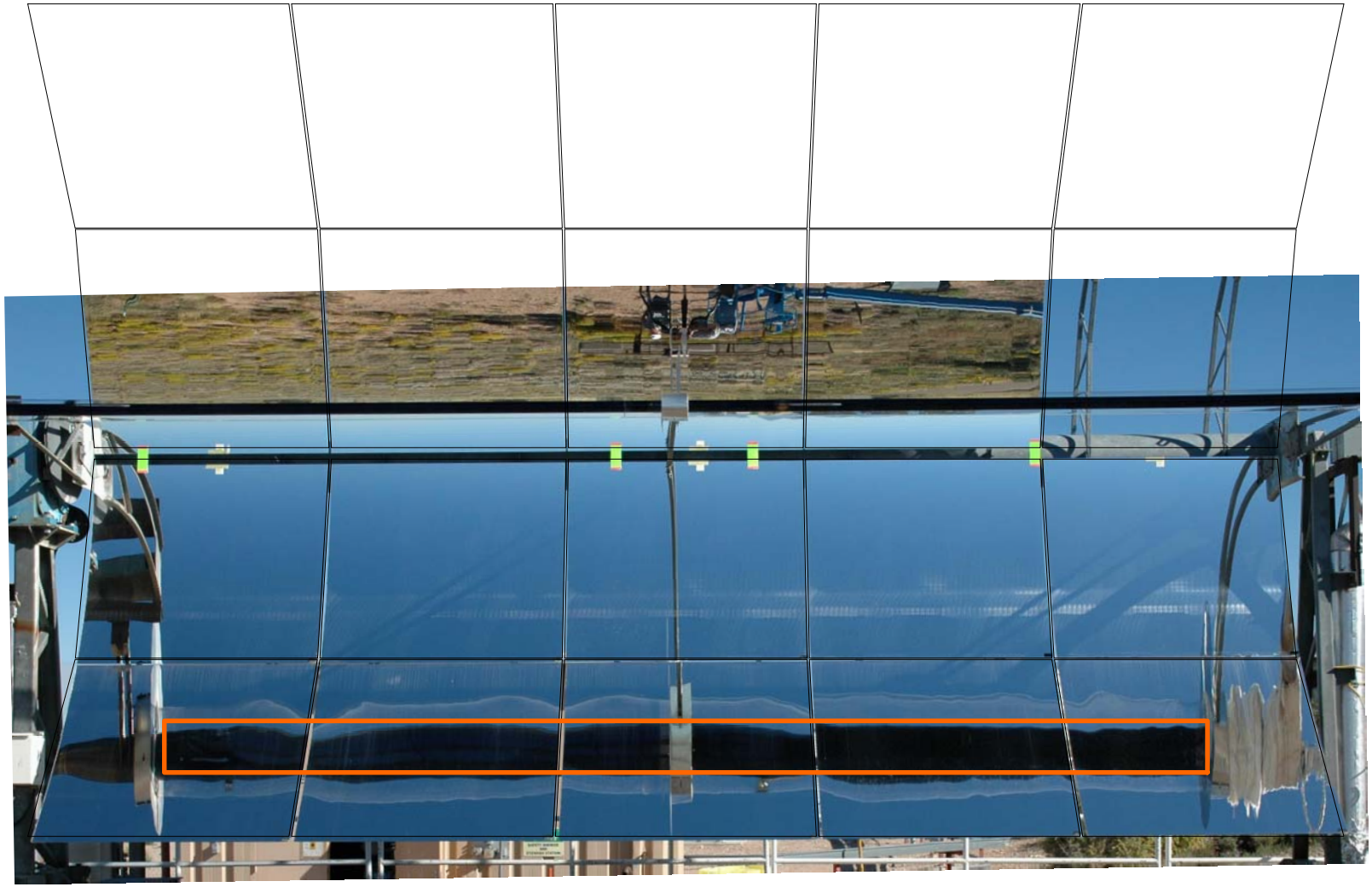
TOP Alignment
Bottom Outer Row (after)



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Estimated TOP Alignment Uncertainty (mm displacement of image in mirror - 95% confidence)

Error	Inner Row Uncert. (± mm)	Outer Row Uncert. (± mm)
Mirror Position, x (± 4 mm)	0	0
Mirror Position, y (± 4 mm)	4	4
Mirror Position, z (± 4 mm)	6	11
Overlay Image Position, y (± 10 mm)	10	10
Image Position, y (± 8 mm)	8	8
Bore Site Position, x (± 50 mm)	0	0
Bore Site Position, y (± 5 mm)	5	5
Bore Site Position, z (± 50 mm)	0	0
Camera Position, y (± 2 mm)	2	2
Trough/Fixture Perpendicularity (±3 deg.)	1	3
Total mirror position uncertainty (mm)	36	43
Total root-sum-square uncertainty (mm)	15.7	18.4

Slope errors (y) result in 18mm/mrad (Inner row) and 21 mm/mrad (Outer row)

One sigma uncertainty < 1mrad

Alignment error < ½ mirror slope error

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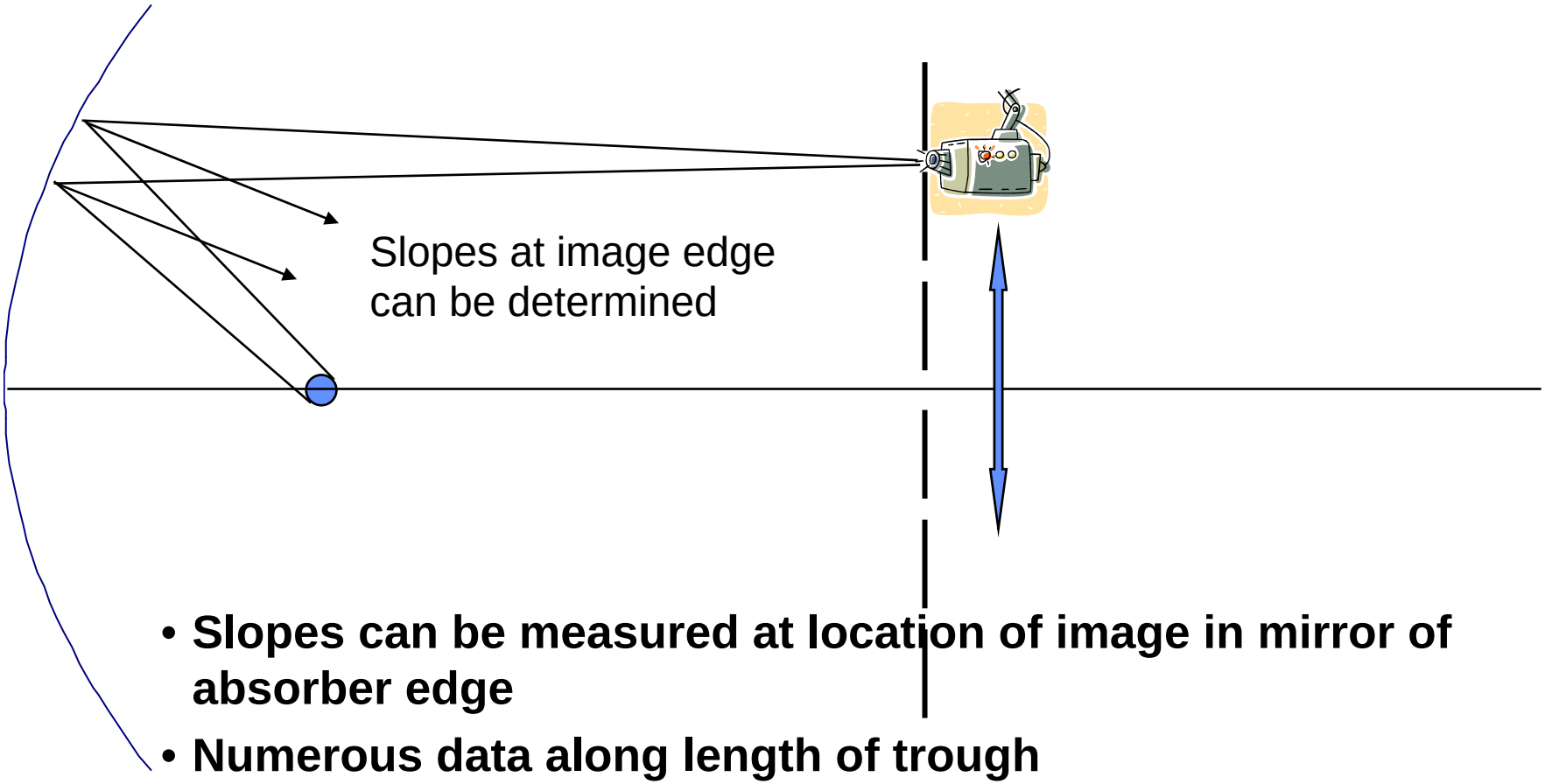
TOP Alignment - Practical Field Implementation

- Trailer mounted fixture towed through field
  - Troughs pointed horizontally (± 1º)
  - Stop when middle (boresight) camera frames module
  - Guided by agriculture plowing technology
  - Raise or lower to boresight fixture, take images, move on
- Field crew installs/removes sight gages and survey guides
- Post-process data and align later
  - Possibly align while trough operates
  - Quality control alignment check as appropriate

Proposed Alignment - Possible Advanced Techniques



- **Slopes can be measured at location of image in mirror of absorber edge**
- **Numerous data along length of trough**
- **Multiple measurement locations along fixture could provide sufficient data to optically characterize trough module quickly and with high spatial resolution**

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TOP Alignment - Path Forward for FY 06 and Beyond

- Recommend SNL – NREL collaboration with complementary development paths
  - SNL Develop Practical Field Alignment
  - NREL develop advanced module characterization techniques
  - SNL/NREL collaborate on both fronts
- Work with Solergenix and FPL
  - Characterize/align APS Saguaro and Kramer LS-2 loops
- Patent technical advance submitted
  - This meeting constitutes “public disclosure”
  - We have one year from now to patent

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Another Improvement Opportunity

- **Moment-joint mirror mounts can significantly distort mirrors**
- **Commonly seen with direct optical feedback on dishes**
- **Significant distortion seen with more compliant mounts on stiffer mirrors that on the LS-2**

Mount Induced Distortion

Mount Removed

TOP Alignment Summary

- Theoretical Overlay Photographic technique for trough alignment conceived and shown to be viable
- Potential significant improvement
  - Increased intercept
  - Increased concentration (smaller HCE)
  - Reduced fixture accuracy requirements & cost
- TOP alignment is accurate and practical
  - Alignment accuracy of <1 mrad
  - Inherently aligns mirrors to HCE
  - Suitable for large trough installations
- TOP alignment approach should be developed
  - Demonstrate alignment in real trough world (Saguaro, Kramer)
  - Module characterization capability should be developed
  - Mirror mount distortion issues deserve attention

Questions?

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